of an appropriate volume to 100 ml. resulted in a solution of the desired buffer concentration. In a similar way the phenols were accurately weighed out and dissolved in the solvent so that 40 ml. of the solution (or 80 ml. where the solubility of the phenols was low), diluted to 100 ml., provided a solution 0.008 $M$ in phenol. In acetic acid the phenol concentration was 0.004 $M$. The iodide–iodine stock solution was ten times stronger than the final concentration and 10-ml. portions were used. The final concentration of potassium iodide was 0.12 $M$ in 30% methanol, 0.03 $M$ in 10% acetic acid and 0.1 $M$ in the remaining solvents. The actual kinetic runs were conducted as described before.[4] Reaction was usually followed up to 50–60%, except in the case of *p*-*n*-butylphenol where an upward drift was noted after 40% reaction. Rate constants were calculated from the integrated form of the second-order rate equation. They are expressed in liters mole$^{-1}$min.$^{-1}$. All runs were conducted at least in duplicate. The results of two runs are given in Table III. With few exceptions the average deviations in the rate constants within each run, and in the average rate constants listed in Table I, were 2% or less.

TABLE III

THE IODINATION OF *p*-*t*-BUTYLPHENOL AT 25° IN 30% METHANOL

*p*-*t*-Butylphenol 0.008005 $M$, $I_2$ 0.002 $M$, $KH_2PO_4$ 0.025 $M$, $Na_2HPO_4$ 0.0125 $M$, KI 0.12 $M$

| Time, min. | 0.01990 $M$ thiosulfate, ml. | $k_2$, liters mole$^{-1}$ min.$^{-1}$ |
|---|---|---|
| 0 | 1.951 | . . |
| 8 | 1.790 | 1.36 |
| 17 | 1.626 | 1.37 |
| 24 | 1.517 | 1.35 |
| 33 | 1.381 | 1.36 |
| 49 | 1.180 | 1.35 |
| 57 | 1.100 | 1.34 |
| 64 | 1.021 | 1.35 |
| 74 | 0.912 | 1.39 |

THE IODINATION OF *p*-CRESOL AT 25° IN 10% ACETIC ACID

*p*-Cresol 0.00410, $I_2$ 0.002 $M$, NaAc 1 $M$, KI 0.03 $M$

| Time, min. | 0.02 $M$ thiosulfate, ml. | $k_2$, liters mole$^{-1}$ min.$^{-1}$ |
|---|---|---|
| 0 | 1.961 | . . |
| 11.5 | 1.865 | (1.08) |
| 28 | 1.722 | 1.17 |
| 47 | 1.582 | 1.17 |
| 57 | 1.522 | 1.15 |
| 73 | 1.420 | 1.16 |
| 90 | 1.317 | 1.18 |
| 111 | 1.210 | 1.18 |
| 122 | 1.153 | 1.19 |

The dissociation constants of the phenols in 50% (by volume) ethanol–water, obtained without activity corrections from the reading of the *p*H of a half-neutralized solution on a Leeds and Northrup *p*H meter calibrated with aqueous buffer solutions, had the following values: ($K \times 10^{12}$) *p*-H 5.5, *p*-Me 2.5, *p*-Et 2.35, *p*-*i*-Pr 2.7, *p*-*t*-Bu 2.35. The ratio *p*-*t*-Bu/*p*-H (0.43) is similar to that obtained in 23% aqueous butanol (0.48),[17] and the value for the *p*K of phenol (11.26) falls between those reported for 40 and 60% ethanolic solutions (10.93 and 11.60).[18]

**Acknowledgment.**—Part of this work was aided by a Frederick Gardner Cottrell Grant of the Research Corporation, which we gratefully acknowledge.

[17] W. H. Fletcher, THIS JOURNAL, **68**, 2727 (1946).

[18] M. Mizutani, *Z. physik. Chem.*, **118**, 326 (1925).

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF MICHIGAN]

# Unsaturated Sulfonic Acids. III. Bromination and Brominolysis of *p*-Substituted 2-Phenylethene-1-sulfonic Acid Derivatives[1]

BY CHRISTIAN S. RONDESTVEDT, JR., AND JAMES C. WYGANT[2]

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The electronic theory predicts that electrophilic attack on the double bond in β-arylethenesulfonic acids should be retarded by electron-withdrawing groups in the para position and accelerated by electron-releasing groups. This prediction was confirmed by bromination of *p*-nitro-, *p*-methoxy-, *p*-hydroxy-, *p*-amino- and *p*-acetamidophenylethenesulfonic acids. A bromine atom enters the side chain *alpha* to the sulfo group, and the process involves substitution rather than addition. With the more active rings, nuclear bromination competes with side-chain bromination. Excess bromine displaces the aromatic ring from the *p*-amino-, *p*-hydroxy- and *p*-methoxy-substituted sulfonates. It is suggested that a benzyl-type alcohol is the intermediate which is cleaved by a mechanism analogous to aromatic substitution. The side-chain appeared as bromosulfoacetaldehyde, the ring as tribromoaniline or tribromophenol. A similar cleavage occurs on bromination of *p*-hydroxycinnamic acid in water.

Our previous work with unsaturated sulfonic acid derivatives showed that they would react with nucleophilic reagents such as cyclopentadiene. As the compound *p*-$YC_6H_4CH{=}CHSO_2X$ was modified by increasing the electron-attracting ability of groups X and Y, its dienophilic powers were enhanced. Thus, sulfonyl chlorides were more reactive than methyl esters, and a *p*-nitro compound more than the unsubstituted derivative.[3] Since the reactivities were in accord with the predictions of the electronic theory, we sought further information about the behavior of the double bond by studying the reaction with bromine. It is well-known that electrophilic bromine addition to ethylenes is accelerated by electron-releasing groups and impeded by electron-withdrawing groups attached to the double bond.[4,5] It had been found previously that 2-phenylethene-1-sulfonyl chloride and 2-phenylethene-1-sulfonamide add bromine very slowly in the absence of catalysts.[6] However,

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[1] Presented in part at the A.C.S. Meeting in Milwaukee, April 1952. Abstracted from a portion of the Ph.D. Dissertation of J. C. Wygant, University of Michigan, 1952.

[2] The junior author is indebted to Abbott Laboratories and to the Allied Chemical and Dye Corporation for fellowships held during this work.

[3] (a) C. S. Rondestvedt, Jr., and J. C. Wygant, THIS JOURNAL, **73**, 5785 (1951); (b) *J. Org. Chem.*, **17**, 975 (1952).

[4] S. V. Anantakrishnan and C. K. Ingold, *J. Chem. Soc.*, 1396 (1935).

[5] P. de la Mare and P. W. Robertson, *ibid.*, 2838 (1950), and earlier papers.

[6] F. G. Bordwell and C. S. Rondestvedt, Jr., THIS JOURNAL, **70**, 2429 (1948).

sodium ethenesulfonate[7] and sodium 2-phenylethene-1-sulfonate[6] react very rapidly with bromine water—by α-substitution.

In this paper, we report the effect of a series of para substituents on the ease of bromination of 2-phenylethene-1-sulfonic acid salts. No attempt was made to determine rate constants, since the initial reaction with all but the nitro compound was practically instantaneous at room temperature in aqueous solution.

## Results

The compounds studied were prepared by standard methods from 2-*p*-nitrophenylethene-1-sulfonyl chloride.[8] The code numbers are given in Table I.

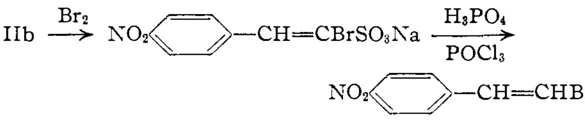
TABLE I

$p-YC_6H_4CH{=}CHSO_2X$

| Code | Y | X | Code | Y | X |
|---|---|---|---|---|---|
| I | H | ONa | IIIb | $NH_2$ | $NH_2$ |
| IIa | $NO_2$ | Cl | IIIc | $NH_2$ | $NEt_2$ |
| IIb | $NO_2$ | ONa | IV | OH | ONa |
| IIc | $NO_2$ | $NH_2$ | V | $OCH_3$ | ONa |
| IId | $NO_2$ | $NEt_2$ | VI | NHAc | ONa |
| IIIa | $NH_3^+$ | $O^-$ | | | |

**Bromination of IIb.**—The very rapid conversion of sodium 2-phenylethene-1-sulfonate to sodium 2-phenyl-1-bromoethene-1-sulfonate[6] should be retarded by the introduction of a *p*-nitro group. This prediction was confirmed; 40 hours were required for the substitution of one atom of bromine into IIb. One mole of hydrogen bromide was produced, indicating substitution rather than addition. The location of the bromine atom alpha to the sulfo group was confirmed by desulfonation to *p*-nitro-β-bromostyrene, which was identified by brominating to 1,1,2-tribromo-2-*p*-nitrophenylethane.[9]

As expected, no ring bromination occurred with excess bromine.



**Brominations of V and VI.**—The reference compound I reacts so rapidly with bromine water that no increase in rate was apparent when electron-releasing substituents were introduced into the para position. It was of interest, however, to establish the reactivity of the side chain in competition with the activated aromatic rings present in compounds III–VI. Sodium 2-*p*-acetamidophenylethene-1-sulfonate (VI) reacted with one mole of bromine by substitution at the side chain. With V, however, after the first mole of bromine had reacted by substitution, the product could be oxidized to a mixture of *p*-anisic acid and 3-bromo-4-hydroxybenzoic acid.[10]

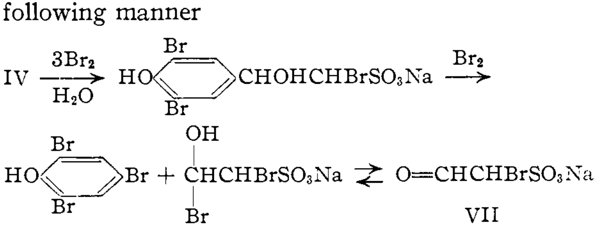
Each compound reacted fairly rapidly with two moles of bromine by substitution. The structures of the products were shown by oxidation to good yields of 3-bromo-4-methoxybenzoic acid and 3-bromo-4-acetamidobenzoic acid, respectively; the alpha position of the side-chain bromine is assumed by analogy.[6]

When three moles of bromine reacted with V at room temperature, a small amount of tribromo*phenol* was produced by brominolysis of the side chain (see below) *and* ether cleavage. At 0°, there was no ether cleavage. With four or more moles, the additional bromine reacted with the displaced side chain, since the colorless filtrate liberated iodine from potassium iodide. The behavior of VI was qualitatively similar (see Experimental).

**Brominations of III and IV.**—With one or two moles of bromine, the results were ambiguous. When IV reacted with three moles of bromine at room temperature, substantial brominolysis was observed. At 0°, however, cleavage was suppressed and it was possible to isolate (as the *p*-toluidine salt), a 59% yield of what is presumed to be 2-hydroxy-2-(3,5-dibromo-4-hydroxyphenyl)-1-bromoethane-1-sulfonic acid. Three moles of hydrogen bromide was liberated. The structure is assigned on the basis of elementary analysis, the neutral equivalent of the *p*-toluidine salt,[11] by the manner of formation in aqueous solution, by oxidation of the acetylated sodium salt to 3,5-dibromo-4-acetoxybenzoic acid, and by the fact that its ultraviolet absorption spectrum was radically different from the spectra of an extensive series of 2-arylethene-1-sulfonic acid derivatives (Fig. 1).[12] Furthermore, the brominolysis of this intermediate is readily understandable on the basis of the benzyl-type alcohol structure (see below). While this assignment of structure is tentative, it is consistent with the available data.

Salts IIIa and IV behaved alike toward four moles of bromine, precipitating tribromoaniline (82%) and tribromophenol (70%), respectively, after a few minutes at room temperature. Both IIIb and IIIc reacted with approximately four moles of bromine in aqueous acetic acid to precipitate high yields of tribromoaniline.

**Bromosulfoacetaldehyde (VII).**—The brominolysis described above may be represented in the following manner



The side chain appears as VII. In one experi-

(7) E. P. Kohler, *Am. Chem. J.*, **20**, 680 (1898).

(8) F. G. Bordwell, A. B. Colbert and B. Alan, THIS JOURNAL, **68**, 1778 (1946).

(9) S. Reich and N. Chang, *Helv. Chim. Acta*, **3**, 235 (1920), give no analysis, and their melting point (83°) does not agree with ours (68.5–70.0°). They also give incorrect melting points for the *cis* and *trans* olefins; *cf.* A. Dann, A. Howard and W. Davis, *J. Chem. Soc.*, 607 (1928).

(10) Compare the bromination of acet-*p*-anisidide exclusively ortho to the methoxyl group; E. Bures and M. Loucek, *Casopis Ceskoslov Lekarnictva*, **8**, 295 (1928); *C. A.*, **23**, 2675 (1929).

(11) The mole of water added to the double bond is required by the analytical data. It is possible that this water is present merely as a hydrate, but it seems unlikely. O. C. Dermer and C. H. Dermer, *J. Org. Chem.*, **7**, 581 (1942), reported that only three out of approximately 190 aniline and toluidine salts retained water on air drying; these three readily lost the water on heating. Our sample was dried for one hour at 78° (0.03 mm.).

(12) C. S. Rondestvedt, Jr., and Andrew DeRocco, unpublished work.

ment, IIIa was treated with four moles of bromine, and a 7% yield of unstable sodium bromosulfoacetaldehyde hemiacetal was isolated from the filtrate. In other experiments in which IV was treated with four moles of bromine, the filtrates gave yields of 54–61% (based on original sodium sulfonate) of glyoxal phenylosazone when treated with phenylhydrazine; from similar brominations of IIIa, the yields were 64–66%. However, when three or five moles of bromine was used, only traces of osazone were obtained. The filtrate from a five-mole bromination of IIIa was treated with sodium iodide; after extraction of the liberated iodine, an 81% yield of glyoxal *p*-bromophenylosazone was obtained.

Bromosulfoacetaldehyde, hitherto unknown, was synthesized in 10% yield (based on olefin) by the sulfonation of 1,2-dibromoethene with sulfur trioxide, and isolated as its hemiacetal; the procedure was like that for chlorosulfoacetaldehyde.[13] It appears that the ethionic anhydride-type intermediate common to many olefin sulfonations is involved here.

**Bromination of *p*-Hydroxycinnamic Acid.**—When the acid was brominated in an *aqueous* slurry, 52% of tribromophenol was isolated, accompanied by a mixture of brominated cinnamic acids. The aqueous filtrate produced 37% crude, 17% purified yield of glyoxal phenylosazone on treatment with phenylhydrazine.

The acid has hitherto been brominated in nonaqueous solvents,[14] and the product is 3,5-dibromo-4-hydroxycinnamic acid dibromide. We had occasion to convert this product to 1-(3,5-dibromo-4-hydroxyphenyl)-2,2-dibromoethanol by Zincke's method in connection with a structure proof. The structure of the latter was established by hypobromite oxidation to 3,5-dibromo-4-hydroxybenzoic acid and by phosphorus pentoxide dehydration to 2 - (3,5 - dibromo - 4 - hydroxyphenyl) - 1,1 - dibromoethene.

## Discussion

The qualitative effect of the nitro group upon the speed of bromination is in accord with theory. The magnitude of the effect is much greater than expected. If the reference compound I is said to react completely in one minute,[15] then I reacts at least 2400 times as fast as IIb. By way of contrast, methyl cinnamate reacts with bromine only four times as fast as methyl *p*-nitrocinnamate.[16] A comparison of I with compounds III–VI is complicated by concurrent ring bromination. The relative reactivities of the rings in IIa–VI toward bromination are in line with previous experience.[10]

Brominations of IIIa and IV appear to follow parallel courses. Since the methoxyl group is sufficiently ring-activating to permit nuclear bromination to compete with side-chain substitution, it is reasonable to propose that the much more strongly electron-releasing amino and hydroxyl groups direct at least the first and probably also the second mole of bromine to the positions ortho to themselves. The molecule would then react more slowly at the side chain. The electron-releasing group should favor the reaction of the intermediate bromonium ion with water (bromohydrin formation) over the competing elimination of a proton.

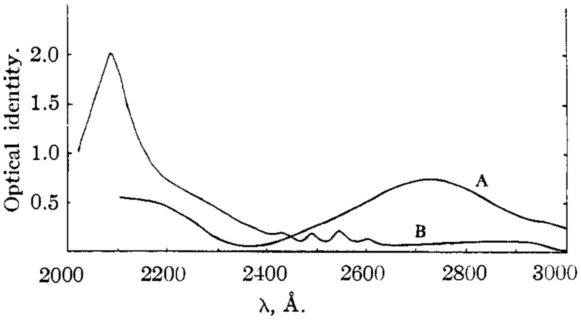


Fig. 1.—Ultraviolet absorption spectra in 95% ethanol: A, sodium 2-*p*-hydroxyphenylethene-1-sulfonate; B, sodium 1 - bromo - 2 - hydroxy - 2 - (3,5 - dibromo - 4 - hydroxyphenyl)-ethane-1-sulfonate.

Secondary benzyl-type alcohols are susceptible to brominolysis, as several workers have shown.[17-22] In a series of +T-substituted benzhydrols, the yields of cleavage products were in the same order as the electron-releasing tendency of the group, *viz.*, $Me_2N > OH > OMe > Me$.[17b] The parallel series of substituted diphenylmethanes was cleaved less readily, and the benzophenones not at all.[17b] It appears that when a group capable of existing as a stable fragment (or its conjugate acid) is attached to a ring para to a +T-substituent, bromine *may* displace this group. Other halogens are somewhat similar. Thus 3,5-dibromo-4-aminobenzenesulfonic acid is cleaved by iodine monochloride to 4-iodo-2,6-dibromoaniline; it also is cleaved by chlorine, but the product is a mixture of tribromoaniline and the expected chlorodibromoaniline.[23]

We noted that chlorine did not form trichlorophenol from IV. However, chlorination of the reaction product from IV and three moles of bromine did produce a mixture of tribromophenol and dibromochlorophenol in which the former predominated; iodine monochloride failed to cleave the intermediate. The partial success of chlorine seems to stem from its ability to displace bromine, either from the ring or from the bromosulfoacetaldehyde, which iodine monochloride is incapable of doing.[23] Bromine is a much more effective cleavage agent, but this fact is not in accord with its relative electrophilicity. Acids alone do not split the intermediate, since prolonged heating of a strongly acid solution resulting from the bromination of IV with three moles of bromine produced no detectable dibromophenol.

In attempting to formulate a mechanism to

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(13) H. Le Pouse, *Bull. soc. chim. Belg.*, **32**, 139 (1923); **34**, 133 (1925).

(14) T. Zincke and F. Leisse, *Ann.* **322**, 186, 225 (1902).

(15) Bromine absorption actually occurs as fast as saturated bromine water can be poured in.

(16) I. Hartman and P. W. Robertson, *J. Chem. Soc.*, 891 (1945).

(17) (a) L. Clarke and G. Esselen, THIS JOURNAL, **33**, 1135 (1911); (b) E. P. Kohler and R. Patch, *ibid.*, **38**, 1205 (1916).

(18) F. Beilstein and P. Geitner, *Ann.*, **139**, 2 (1866).

(19) E. Schunck and L. Marchlewski, *ibid.*, **278**, 348 (1893).

(20) R. Schmitt, *ibid.*, **120**, 137 (1861).

(21) J. Obermiller, *Ber.*, **42**, 4361 (1909).

(22) G. Hennion and J. Anderson, THIS JOURNAL, **68**, 424 (1946); D. I. Legge, *ibid.*, **69**, 2086 (1947).

(23) J. Sudborough and J. Lakhumalani, *J. Chem. Soc.*, **111**, 45 (1917).

TABLE II

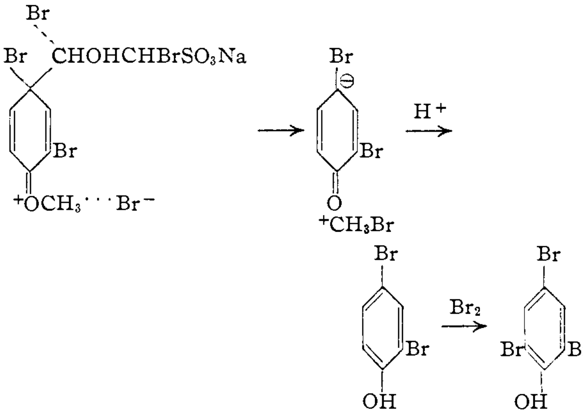
PROPERTIES OF *p*-SUBSTITUTED STYRENESULFONATES

| Cpd.[a] | Cryst. solv.[b] | Analyses, % Carbon Calcd. | Carbon Found | Hydrogen Calcd. | Hydrogen Found | Sodium Calcd. | Sodium Found | Benzylthiuronium salt, m.p., °C. | Cryst. solv.[b] | Analyses, % Carbon Calcd. | Carbon Found | Hydrogen Calcd. | Hydrogen Found | Nitrogen Calcd. | Nitrogen Found |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IIb | E | | | | | | | 214–215 | EW | 48.67 | 48.54 | 4.32 | 4.21 | | |
| | | | | | | | | 260–263 dec.[c] | W | 53.58 | 53.68 | 4.80 | 4.55 | | |
| IId | EW | 50.70 | 50.99 | 5.67 | 5.38 | | | | | | | | | | |
| IIIa | W | 48.25 | 48.11 | 4.55 | 4.37 | | | 167–169 | APW | | | | | 11.50 | 11.36 |
| IIIc | EW | 56.66 | 56.81 | 7.13 | 7.23 | | | | | | | | | | |
| IV | W | | | | | 10.35 | 10.18 | 156.7–157.8 | EW | | | | | 7.69 | 7.68 |
| V | EW | | | | | 9.73 | 9.67 | 153–154 | AW | 53.66 | 53.97 | 5.29 | 5.35 | 8.16[d] | 8.21[d] |
| VI | E | | | | | 8.74 | 8.43 | 193–194.5 | EW | | | | | 10.32 | 10.11 |

[a] IId, m.p. 117.5–119°; IIIc, 123.5–125°. [b] E = ethanol; W = water; A = acetonitrile; P = acetone. [c] *p*-Toluidine salt. [d] % $OCH_3$.

explain the observed phenomena, we are impressed by the correlation of the ease of cleavage with the relative abilities of groups to promote electrophilic substitution in the benzene ring. The attack may be led by the positive end of a polarized bromine molecule, with water functioning as a polarizing base. The activated complex is then decomposed by an anion, the more nucleophilic bromide ion being far more effective than chloride ion. We prefer this explanation to the simpler one in which the driving force is derived from the restoration of the aromatic ring, since the latter provides no explanation for the surprising unreactivity of chlorine.

The methoxyl cleavage noted when V reacted with excess bromine can also be explained by a similar picture. Ether cleavage does not occur *after* the side-chain has been displaced, since in control experiments it was found that anisole, 2,4-dibromoanisole, or 2,4,6-tribromoanisole are not converted to base-soluble material by bromine water containing large amounts of hydrobromic acid. It is suggested that in the activated complex brought about by the electrophilic attack of bromine, the positively-charged ether oxygen is displaced by the bromide ion (which is in plentiful supply) before or simultaneously with the cleavage of the side chain. (No attempt was made to isolate methyl bromide.)



It is unnecessary to require participation in the cleavage by the sulfonate anion.

The rate of cleavage is not markedly greater than the rate of bromination of VII. The difference in rates should be greater with the more reactive IIIa than with IV, and this was observed. The amino derivative liberated 82% of the expected tribromoaniline with four moles of bromine, compared to 70% of tribromophenol from IV. Although authentic VII produced a quantitative yield of glyoxal phenylosazone, the yields of osazone from four-mole brominations of IIIa and IV were always smaller than the yields of tribromo compound. When five moles of bromine was employed, the yields of tribromoaniline and tribromophenol could be raised to 93 and 84%, respectively, but filtrates from these reactions produced only traces of osazone. With authentic VII, the other α-hydrogen of bromosulfoacetaldehyde is replaceable by bromine, and the second bromine is readily reduced by hydrogen iodide. The 81% yield of osazone obtained from a five-mole bromination of IIIa which was followed by iodide treatment is thus explainable.

## Experimental

Compounds IIa, IIc and IIIb are known.[8] Some experimental details and derivatives[24] for the other compounds prepared are recorded in Table II.

**Sodium 2-*p*-Nitrophenylethene-1-sulfonate (IIb).**—A mixture of 5 g. of IIa and an equivalent of sodium carbonate was heated in 30 ml. of 50% aqueous methanol for about 1 hour. After filtering and evaporating to dryness, the residue was extracted with hot 95% alcohol. The extract on cooling deposited 3.44 g. (68%) of IIb containing a trace of chloride ion.

**N,N-Diethyl-2-*p*-nitrophenylethene-1-sulfonamide (IId)**—A solution of 6 g. (0.024 mole) of IIa in 100 ml. of acetone was treated with 6 g. (0.082 mole) of diethylamine. After 15 minutes, several volumes of water were added, and the product was collected and washed with water; 5.3 g. (77%) (recrystallized).

**N,N-Diethyl-2-*p*-aminophenylethene-1-sulfonamide (IIIc).**—To a solution of 7.2 g. of stannous chloride in 9 ml. of concentrated hydrochloric acid was added 3 g. (0.0106 mole) of IId. After a little warming on the steam-bath, some heat was evolved and a slushy precipitate settled. After 15 minutes heating on the steam-bath, the solid (now granular) was collected and treated with 20 ml. of 20% sodium hydroxide to dissolve tin salts. The crude product was dissolved in dilute hydrochloric acid and a little unreacted IId filtered off; the IIIc was reprecipitated with dilute sodium hydroxide; recrystallized yield 1.58 g. (59%).

**2-*p*-Aminophenylethene-1-sulfonic Acid (IIIa).**—A mixture of 3 g. (0.0121 mole) of IIa, 1.3 g. of sodium carbonate, 15 ml. of water and 10 ml. of methanol was heated on the steam-bath for one hour with stirring. The hot solution was poured into a boiling solution of 24 g. of ferrous sulfate heptahydrate and 50 ml. of water. About 25 ml. of concd. ammonium hydroxide was added in small amounts until the solution remained basic. The mixture was boiled for five minutes more, filtered, acidified with 2 ml. of concd. sulfuric acid and the orange-yellow needles were collected after standing, washed with aqueous alcohol, and dried in a desiccator. The product weighed 1.85 g. (76%); neut. equiv., 198 (calcd. 199). The analytical sample was recrystallized twice from water, avoiding prolonged boiling which produced some decomposition.

**Sodium 2-*p*-Hydroxyphenylethene-1-sulfonate (IV).**—The aminosulfonic acid IIIa (11 g., 0.0552 mole) was dis-

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(24) F. G. Bordwell, C. M. Suter, J. M. Holbert and C. S. Rondestvedt, THIS JOURNAL, **68**, 139 (1946).

solved in dilute alkali containing 4.2 g. of sodium nitrite. The mixture was cooled in an ice-bath and rapidly stirred, while excess acid was added rapidly. The insoluble diazonium sulfonate was then collected and washed with a small amount of cold water, then alcohol, then ether. After air drying for 2 hours, the diazonium salt weighed 9.99 g. (0.0473 mole). It was added all at once to 800 ml. of boiling water, and the solution was boiled for 20 minutes. An equivalent amount of sodium carbonate (2.51 g.) was added, and the solution was boiled five minutes more with Norite. Most of the water was removed under reduced pressure, and the solution was allowed to crystallize. The salt was collected and washed with cold 50% alcohol. Two more crops were obtained by evaporation; the three crops totaled 7.51 g. The product was a tan powder. On recrystallization from water a 60% yield was obtained in two crops.

**Sodium 2-*p*-Methoxyphenylethene-1-sulfonate (V).**—Five grams (0.0225 mole) of IV was dissolved in 25 ml. of water containing 36 ml. of 5% sodium hydroxide. A solution of 5.67 g. of dimethyl sulfate in 20 ml. of ethanol was added with stirring in one hour. The solution became warm and a solid separated. The mixture was then heated on the steam-bath for 30 minutes. On cooling, the product separated in large crystals. After being washed with 50% alcohol, it weighed 3.45 g. (65%).

**Sodium 2-*p*-Acetamidophenylethene-1-sulfonate (VI).**—A mixture of 5 g. (0.025 mole) of IIIa, 20 ml. of pyridine and 20 ml. of acetic anhydride was heated on the steam-bath for 1.5 hours. After standing overnight, the excess reagents were distilled under reduced pressure. Three successive 25-ml. portions of absolute alcohol were added and the vacuum evaporation repeated. The red oily residue was neutralized with 5 ml. of 20% sodium hydroxide, causing the separation of 2.24 g. of sodium sulfonate. Evaporation of the filtrate and addition of alcohol gave a second crop of 1.67 g.; total yield 59%.

**Brominations; General Procedure.**—The brominations were carried out by dissolving or suspending the compound in water and adding the desired quantity of bromine, either in the form of standard potassium bromate (plus potassium bromide and hydrochloric acid), or by using freshly standardized, approximately 0.1 *M* bromine water. Unreacted bromine was determined iodometrically. In some cases, the products were oxidized with neutral or slightly alkaline permanganate at 100° for 1–3 hours. The acids were isolated either by filtering the manganese dioxide and acidifying, or by reducing it with acidified bisulfite. Known compounds were identified by m.p. and mixed m.p. with authentic samples.

**Reaction of IIb with Bromine.**—A sample of IIb was treated with slightly more than 1 molar equivalent[25] of bromate.

In 12 hours, 0.75 mole of bromine had been absorbed; in 27 hours, 0.90 mole of bromine; in 42 hours, 1.01 moles. A sample which stood for three days with a three-mole excess of bromine consumed 1.02 moles of bromine.

**Sodium 2-*p*-Nitrophenyl-1-bromoethene-1-sulfonate.**—A sample of IIb was allowed to stand four days with excess bromine water. The excess bromine was removed by bubbling nitrogen through the solution. Hydrogen ion (phenolphthalein) and bromide ion (Volhard) were each 0.95 equivalent. After the silver salts resulting from the Volhard titration were removed, the filtrate gave a 65% yield of *p*-nitrobenzoic acid on permanganate oxidation.

Another sample of IIb (2.85 g., 0.0113 mole) in water was allowed to stand for two days with 0.59 ml. of liquid bromine. After two days the mixture was evaporated to dryness at reduced pressure. The dried salt was heated at 100° with 2.36 g. of phosphorus pentachloride for two hours with no apparent results. On adding 5 ml. of phosphorus oxychloride containing phosphoric acid, the salt dissolved, and sulfur trioxide was evolved. After an additional 1.5 hours of heating, the phosphorus oxychloride was removed at reduced pressure. Ice was added and the precipitated ω-bromo-*p*-nitrostyrene (90% yield, m.p. 142–152°) was recrystallized several times from benzene; m.p. 158–160°.

*Anal.* Calcd. for $C_8H_6BrNO_2$: C, 42.12; H, 2.65. Found: C, 42.24; H, 2.73.

It was also produced, in low yield, by strongly heating a paste of the α-bromosodium salt in water to dryness; sulfate ion was also formed. It also could be oxidized to *p*-nitrobenzoic acid.

A solution of 0.228 g. of ω-bromo-*p*-nitrostyrene in 20 ml. of carbon disulfide (or acetic acid) was treated with 0.052 ml. of liquid bromine. After two days the solvent was evaporated, and the remaining oil solidified on trituration with petroleum ether. This tribromo compound was recrystallized from petroleum ether; 0.282 g. (73%), m.p. 66–68.5°. The analytical sample was recrystallized three times more; m.p. 68.5–70° (lit.[9] 83°).

*Anal.* Calcd. for $C_8H_6Br_3NO_2$: C, 24.77; H, 1.56. Found: C, 24.78; H, 1.61.

Finally, ω-bromo-*p*-nitrostyrene was ozonized in ethyl acetate at −80°. After evaporating the solvent, the solid ozonide was boiled with water for 20 minutes. *p*-Nitrobenzaldehyde was isolated as its semicarbazone[26] in 48% yield.

**Bromination of VI.**—A sample (0.387 g.) of VI in water was treated with one molar equivalent of bromine water. There were produced 1.05 equivalents of hydrogen ion and 1.04 equivalents of bromide ion. After filtering the silver salts, permanganate oxidation gave 0.07 g. (26%) of *p*-acetamidobenzoic acid.[27]

When 0.207 g. of VI in water was treated with two molar equivalents of bromine water, the first was decolorized almost instantly; the second required one-half to one hour. Permanganate oxidation gave 0.09 g. (43%) of 3-bromo-4-acetamidobenzoic acid.[28]

When a sample of VI was allowed to stand with four molar equivalents of bromine water, 2.45 moles was consumed in 24 hours and 3.82 moles in 36 hours. A small amount of red precipitate appeared during the reaction. When a sample was allowed to stand with three molar equivalents of bromine until the color had disappeared, 3.06 moles of bromide ion was produced. Again a small red precipitate appeared. It melted at 100–105°; upon recrystallization from petroleum ether, it melted at 102–104°. No further attempt was made to identify it.

**Bromination of V.**—A sample (0.255 g.) was treated with one mole of bromine water. There were produced 1.05 equivalents each of hydrogen and bromide ions. Oxidation with permanganate yielded 0.07 g. of acid, which after three crystallizations from water–alcohol, melted at 165–181°; the acid contained bromine. (Anisic acid melts at 184°.)

A sample (0.232 g.) of V was treated with 2.00 moles of bromine water. Five to 15 minutes were required for the bromine color to disappear. The solution contained 2.02 equivalents of hydrogen ion and 1.98 equivalents of bromide ion. Permanganate oxidation of this solution yielded 0.114 g. (50%) of 3-bromo-4-methoxybenzoic acid.[29]

A solution of 0.208 g. of V in water consumed 3.00 moles of bromine in one to two days at room temperature. A small amount (0.05 g., 17%) of tribromophenol appeared, m.p. 88–91.5°, mixed m.p. 89–92.5°. It was completely base-soluble, but the characteristic odor of 2,4-dibromoanisole was noted. The solution contained 3.39 moles of hydrogen ion and 3.29 moles of bromide ion. Oxidation of the filtrate produced 0.05 g. (26%) of 3-bromo-4-methoxybenzoic acid.

When a solution of V (0.151 g.) was treated with three moles of bromine and set aside in the refrigerator for a day, the precipitate was not base-soluble. It weighed 0.036 g. and melted at 83–92°. It would not crystallize from water–alcohol. Again the odor of dibromoanisole was noted. The filtrate contained 3.16 moles of hydrogen ion and 3.19 moles of bromide ion.

A solution of 0.117 g. of V was allowed to stand 24 hours with four moles of bromine water. The reddish solution remaining after the bromine was gone contained 4.64 moles of bromide ion. The alkali-soluble oily solid weighed 0.04 g., m.p. 84–90°. A solution of V consumed five moles of bromine in two days, and it precipitated tribromophenol (36%).

In several experiments, it was found that the conditions of the reactions would not of themselves affect ether cleavage. Anisole, 2,4-dibromoanisole, or 2,4,6-tribromoanisole was allowed to stand in aqueous solutions of bromine in the presence of hydrochloric acid and potassium bromide. In no case was any base-soluble material obtained.

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[25] That quantity of solution which furnishes one *mole* of bromine per mole of compound.

[26] H. Lan and F. Perkin, *J. Chem. Soc.*, **93**, 1635 (1908).

[27] F. Ullmann and J. Uzbachian, *Ber.*, **36**, 1801 (1903).

[28] L. Raiford and H. Davis, THIS JOURNAL, **50**, 158 (1928).

[29] H. Salkowski, *Ber.*, **7**, 1013 (1874).

**Bromination of IIIb.**—A solution of 0.097 g. of IIIb in 50% aqueous acetic acid was allowed to stand for two days with five molar equivalents of bromate. The unreacted bromine amounted to 1.18 molar equivalents. The precipitate of tribromoaniline weighed 0.14 g. (86%).

**Bromination of IIIc.**—A solution of 0.119 g. of IIIc in 50% aqueous acetic acid was treated with 5 molar equivalents of bromate. After two days, 0.78 mole of bromine remained. The solid which precipitated melted at 80–90° and weighed 0.18 g. (115%, as tribromoaniline); after two recrystallizations, m.p. 118.5–120.5°; mixed m.p. 119–121°.

**Bromination of IV.**—At room temperature, solutions of IV decolorized two moles of bromine instantly. Two more moles of bromine disappeared in fifteen to thirty minutes. Precipitation of tribromophenol began during the addition of the third mole of bromine. At 0°, approximately three hours were required to decolorize four moles of bromine. If the bromine were added carefully, practically no tribromophenol precipitated at 0° during the addition of three moles of bromine.

The average yield of tribromophenol obtained from the reaction of IV with four moles of bromine was 70%, either at room temperature or at 0°. At 70–80°, the yield was only 57%. The precipitate was identified as tribromophenol by its melting point, mixed melting point, and by methylation with diazomethane to tribromoanisole, m.p. 88–90° (lit. 87°).

In the bromination of IV, one mole of bromine produced 0.97 equivalent of bromine ion; two moles, 1.98 equivalents; four moles, 3.92 equivalents; five moles, 4.86 equivalents. Hydrogen ion titrations agreed when brom phenol blue was used as indicator. Phenolphthalein was not satisfactory, since apparently tribromophenol also reacted somewhat with standard alkali.

Five moles of bromine reacted with IV in 18 hours. The yield of tribromophenol was 84%. In the presence of sodium iodide the solution slowly liberated iodine, and after 24 hours, 1.01 moles of iodine was present.

A solution of 0.1 g. of IV was allowed to stand with ten moles of bromine. The initial curdy precipitate of tribromophenol was transformed to a yellow precipitate of tribromophenol hypobromite which weighed 0.161 g. (87%), m.p. about 148° dec., lit.[30] 130° dec. or 118–149° dec., and which gave a red color with benzidine in chloroform. The hypobromite was not obtained unless the quantity of bromine was approximately ten moles.

A solution of 2.10 g. of IV was treated with four moles of bromine. The filtrate was neutralized by the addition of four equivalents of silver oxide, shaking the mixture for about one-half hour, and filtering. It was necessary to add a few drops of dilute hydrochloric acid to remove colloidal silver bromide. The filtrate was concentrated under reduced pressure, giving a solution containing small amounts of halide and sulfate ions. One-tenth of this solution was treated with 0.1 g. each of phenylhydrazine hydrochloride and sodium acetate. The orange precipitate of glyoxal phenylosazone weighed 0.09 g. (110%, based on phenylhydrazine hydrochloride), m.p. 160–164° dec.; after three recrystallizations from water, m.p. 168–170°, mixed m.p. 167–168.5°. In other experiments, the yield of recrystallized osazone was 54, 58 and 61%, based on the original IV. Addition of barium chloride to the filtrate precipitated a mixture of barium sulfate and barium sulfite; the sulfite was detected by its acid solubility. No osazone could be obtained from solutions in which samples of IV had been treated with three (at 0°) or five moles of bromine.

A solution of 0.498 g. of IV was treated with *three* moles of bromine at 0°, and the tribromophenol (3%) was filtered. The filtrate was shaken with 0.778 g. (3 eq.) of silver oxide about one-half hour, filtered and concentrated at reduced pressure to 25 ml. A 5-ml. aliquot of this solution was treated with 0.064 g. of *p*-toluidine hydrochloride in water. On cooling, the *p*-toluidine salt of 1-bromo-2-hydroxy-2-(4-hydroxy-3,5-dibromophenyl)-ethane-1-sulfonic acid precipitated. It weighed 0.15 g. (59%); m.p. 171–173°. After recrystallization from water, the melting point was 172.5–174°; neutral equivalent 280 (calculated 281). A solution of 0.220 g. of IV was treated with *four* moles of bromine, the tribromophenol (60%) and hydrobromic acid were removed, and the concentrated solution was treated with 0.143 g. of *p*-toluidine hydrochloride. The salt weighed 0.117 g. (80%, based on the difference between the original amount of IV and the amount of tribromophenol obtained); m.p. 169–171°. After three recrystallizations, it melted at 173.5–174.5°; mixed m.p. with the preceding salt, 171–173°. The analytical sample was dried at 78° (0.03 mm.) for one hour.

*Anal.* Calcd. for $C_{15}H_{16}Br_3NO_5S$: C, 32.14; H, 2.90. Found: C, 32.08; H, 2.87.

The sodium salt was prepared from 0.0117 g. of the *p*-toluidine salt in 10 ml. of water and the stoichiometric quantity of sodium hydroxide. The solution was extracted with three portions of ether to remove *p*-toluidine, heated gently on the steam-bath to boil out dissolved ether, made up to 25 ml. with water and then diluted to 500 ml. with absolute alcohol.[31]

Another sample of IV (0.541 g.) was treated with three moles of bromine at 0°, and the hydrobromic acid was removed by silver oxide. One-half of the filtrate was evaporated under reduced pressure, dried in a desiccator, and heated for 12 hours with 5 ml. of acetyl chloride. After evaporating the excess acetyl chloride, the residue was dissolved in water and treated with excess permanganate. There was obtained 0.106 g. (26%) of 3,5-dibromo-4-acetoxybenzoic acid.[32] It is assumed that the low yield of the acid resulted from incomplete acetylation, since it was later found that uncatalyzed acetyl chloride was a relatively sluggish acetylating agent for 3,5-dibromo-4-hydroxybenzoic acid.

Other attempts to obtain satisfactory derivatives of the products of bromination of IV were unsuccessful. Samples of IV treated with one, two, or four moles of bromine failed to yield solids with S-benzylthiuronium chloride or with S-*p*-chlorobenzylthiuronium chloride. The use of *p*-phenylaniline hydrochloride as a reagent was investigated briefly. This reagent gave relatively insoluble, nicely crystalline salts, but the melting points proved to be rather insensitive to the presence of impurities. It was not possible to obtain *p*-phenylaniline salts with satisfactory analyses.

A solution of IV was treated with three moles of bromine at 0°. About 3% of tribromophenol was removed, and the solution was freed from hydrobromic acid with silver oxide. An aliquot of this solution treated with another mole of bromine water produced immediately 67% of tribromophenol. Another aliquot was acidified strongly and heated on the steam-bath for 24 hours. No tribromo- or dibromophenol precipitated. Another aliquot was allowed to stand with iodine monochloride in either acetic acid or hydrochloric acid. No precipitate appeared and the solutions were not decolorized after 24 hours. Another aliquot was treated with one mole of standardized chlorine water. The initially colorless solution rapidly became orange-yellow. The precipitate which slowly formed weighed 0.147 g.; after four recrystallizations from water–alcohol or petroleum ether, m.p. 84–85.5°. The melting point of 4-chloro-2,6-dibromophenol is 91–92.5°[33]; tribromophenol melts at 92–94°.

*Anal.* Calcd. for $C_6H_3Br_2ClO$: C, 25.16; H, 1.06. Calcd. for $C_6H_3Br_3O$: C, 21.77; H, 0.91. Found: C, 23.16; H, 1.04.

Additional chlorine passed into this solution did not precipitate more material.

A sample of IV was treated with four moles of chlorine. The chlorine was consumed, but no precipitate appeared. Extraction of the solution yielded only a trace of acidic material which had a strongly phenolic odor and decolorized bromine water.

**Bromination of IIIa.**—Samples of IIIa were suspended in water and treated with four molar equivalents of bromate. Tribromoaniline began to separate after about 2.5 moles had been added. The tribromoaniline was obtained in an average crude yield of 82%. An average of 3.93 moles of bromide ion and 3.83 moles of hydrogen ion were produced.

When samples of IIIa were treated with five moles of bromine, approximately 12 hours were required for complete decolorization. The average yield of tribromoaniline in

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(30) S. C. J. Olivier, *Rec. trav. chim.*, **28**, 354 (1909); S. J. Lloyd, THIS JOURNAL, **27**, 7 (1905).

(31) The ultraviolet spectrum of this solution (Fig. 1) was taken on a Cary recording spectrophotometer, Model 11, Serial 122. The authors are indebted to Mr. Andrew G. DeRocco for taking the spectrum and for his interpretive comments.

(32) W. Robertson, *J. Chem. Soc.*, **81**, 1483 (1902).

(33) W. H. Hunter and F. E. Joyce, THIS JOURNAL, **39**, 2643 (1917).

these experiments was 93%. There were produced 5.04 moles of hydrogen ion and 5.06 moles of bromide ion. When sodium iodide was added to the filtrate, 1.08 moles of iodine was liberated in two days.

A suspension of 0.504 g. of IIIa in water was neutralized with dilute sodium hydroxide. Four moles of bromine water was added, tribromoaniline was filtered off, the hydrobromic acid was removed with silver oxide, and the solution was concentrated under reduced pressure to 25 ml. One-fifth of this solution was treated with 2 molar equivalents of *p*-bromophenylhydrazine hydrochloride (0.19 g.) and 0.3 g. of sodium acetate, resulting in the precipitation of 0.132 g. (66%) of glyoxal *p*-bromophenylosazone, m.p. 226–231° dec., after two recrystallizations from water–alcohol, m.p. 230.5–230.1° dec., mixed m.p. 231–232° dec. Another aliquot formed glyoxal phenylosazone in 54% yield. When samples of IIIa were treated with five moles of bromine, the action of phenylhydrazine on the filtrate produced variable quantities of mixtures which could not be crystallized. The use of *p*-bromophenylhydrazine gave a very small amount of isolable glyoxal *p*-bromophenylosazone. But, when the five-mole bromination filtrate was treated with sodium iodide and the liberated iodine extracted with chloroform, the bromoösazone could be obtained in 81% yield.

A sample of IIIa (0.501 g.) was neutralized and treated with four moles of bromine water. The tribromoaniline (82%) and the hydrobromic acid were removed. The solution was taken to dryness under reduced pressure, and the residue was extracted with two 25-ml. portions of absolute alcohol. Concentration of the alcohol solution gave two crops melting above 300° totalling 0.25 g. which gave no precipitate with phenylhydrazine. The third crop, 0.05 g. (7%), melted at 130–135°; after recrystallization from absolute alcohol, m.p. 138–138.5°; mixed m.p. with sodium bromosulfoacetaldehyde hemiacetal, 136–137°.

**Bromosulfoacetaldehyde.**—*sym*-Dibromoethylene was sulfonated approximately according to the method of Le Pouse for dichloroethylene.[13] Sulfur trioxide (28.3 g., 0.354 mole) was distilled into 49.7 g. (0.267 mole) of dibromoethylene, with stirring and cooling in an ice–salt-bath. The mixture became quite hot, and a thick brown sirup formed. This was poured into ice-water, and the unreacted olefin was separated. One-half of the sulfonation solution was neutralized with sodium carbonate and concentrated under reduced pressure. The residual gummy paste was extracted with 200 ml. of 95% alcohol in four portions. On cooling, 3.44 g. (10%, based on olefin) of the sodium salt of bromosulfoacetaldehyde hemiacetal separated, m.p. 152–153° dec. (Subsequent crops contained sodium bromide.) It was recrystallized from dilute ethanol and analyzed for sodium; calcd. 8.48, found 8.82%. After another recrystallization from alcohol, the material melted at 135.5–137° (varying with the rate of heating). It was extremely hygroscopic.

*Anal.* Calcd. for $C_4H_8BrNaO_5S$: C, 17.72; H, 2.97. Found: C, 18.12; H, 3.24.

A sample of this salt, on treatment with excess phenylhydrazine hydrochloride and sodium acetate, yielded 98% of glyoxal phenylosazone. An authentic sample of osazone was prepared in quantitative yield from the bisulfite addition compound of glyoxal.[34]

In another experiment, sulfur trioxide (21.0 g., 0.263 mole) was distilled into 52.2 g. (0.281 mole) of dibromoethylene with stirring and cooling in an ice–salt-bath. The light brown solution became darker after standing for one hour at room temperature. Heating a portion of this solution caused extensive decomposition with evolution of hydrogen bromide and sulfur dioxide. The remainder was poured into ice-water; after 24 hours, the layer of unreacted olefin was separated. The aqueous layer was made up to 250 ml., and 1-ml. aliquots were analyzed. The solution contained 0.130 mole of sulfate, 0.453 equivalent of hydrogen ion, 0.095 equivalent of bromide ion, 0.101 mole of bromosulfoacetaldehyde (determined as the phenylosazone), and 0.234 mole of total sulfur (determined by oxidation with permanganate, then precipitation of barium sulfate). The yield of bromoacetaldehyde produced but not isolated was thus 38%, based on sulfur trioxide. The solution decolorized a mole of bromine (based on bromosulfoacetaldehyde) quite rapidly. Addition of sodium iodide liberated 1.66 and 2.44 moles of iodine in separate experiments.

**Bromination of *p*-Hydroxycinnamic Acid.**—A slurry of 0.496 g. (0.003 mole) of the acid in 20 ml. of water was treated with four moles of bromine water in small portions, the flask being stoppered and shaken between additions. The mixture was filtered, giving 0.815 g. of material, m.p. 80–100°. The solid was extracted with hot petroleum ether; the residue (presumably brominated *p*-hydroxycinnamic acid) weighed 0.29 g., m.p. 138–160°. The petroleum ether extracts were evaporated, yielding 0.552 g. (52%) of tribromophenol, m.p. 88–90°; after sublimation, mixed m.p. 92.5–93.5°. One-half of the original aqueous filtrate was treated with 0.5 g. of phenylhydrazine hydrochloride, plus sodium acetate. The dark precipitate weighed 0.12 g. (37%), m.p. 135–140° dec. After two recrystallizations from water–alcohol, it weighed 0.05 g. (17%), m.p. 166–168°; mixed m.p. with glyoxal phenylosazone, 167–169°.

**1,1-Dibromo-2-(3,5-dibromo-4-hydroxyphenyl)-ethene.**—This compound was prepared by heating 0.2 g. of 2,2-dibromo-1-(3,5-dibromo-4-hydroxyphenyl)-ethanol[14] and 0.2 g. of phosphorus pentoxide at 150° for about 10 minutes; the product was then sublimed directly from the reaction. The yield was 0.11 g. (57%), m.p. 94–98°; after recrystallization from petroleum ether, m.p. 99.5–100.5°.

*Anal.* Calcd. for $C_8H_4Br_4O$: C, 22.05; H, 0.925. Found: C, 22.07; H, 0.856.

The alcohol[14] (0.3 g.) was dissolved in 5 ml. of 0.5 *M* NaOH, and to the cooled solution was added a solution of 0.07 ml. of liquid bromine in 5 ml. of sodium hydroxide. The solution was kept at about 60° for one hour, then acidified, and the product was collected. The crude acid weighed 0.12 g. (64%); after two recrystallizations from nitromethane, m.p. 264–267° dec., mixed m.p. with 3,5-dibromo-4-hydroxybenzoic acid,[32] 265–268.5° dec.

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(34) H. Debus, *Ann.*, **102**, 20 (1857).